AN INVESTIGATION OF SOUND MEASUREMENT CHANGES RESULTING FROM MODIFICATIONS TO A SEMI-REVERBERANT SOUND CHAMBER

A Thesis

by

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ABSTRACT

The RELLIS Energy Efficiency Laboratory, REEL, is a research and testing facility established in 1939 and an approved testing laboratory for HVI. Testing of residential ventilation devices is one of the main applications of this laboratory. Recently, the microphones for the sound chamber were changed from free-field to diffuse. The test method and procedure for measuring sones is understood, but the effect of using a different microphone type to record sound pressure levels is not. The need to understand the effects of changing equipment in sound facilities is necessary in order to provide accurate and verifiable test results.

This study investigates the change in sone ratings between free-field and diffuse microphones by using the sound facilities at REEL. A total of 96 trials for eight different residential ventilation devices was performed to record sone levels over a range of less than 0.3 to 11.5 rated sones. This analysis found that there was less than a 4% difference in sone values measured when using the different microphone types.

Additionally, the change in sone ratings using different resonant sound sources (RSS) was analyzed using the same data from the 96 trials. From this data, it was determined that there was a negligible difference from using the different RSS devices.

DEDICATION

This thesis is dedicated to my loving parents for always supporting me and in loving memory of my best friend and canine companion, Daisy.

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Contributors

This work was supervised by a thesis committee consisting of Dr. Pate and Dr. Hogan of the Department of Mechanical Engineering, as well as Dr. King of the Department of Biological & Agricultural Engineering.

All work conducted for the thesis was completed by the student independently.

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NOMENCLATURE

ANSI	American National Standards Institute
B&K	Bruel and Kjaer Sound and Vibration
Db	Decibel
K	Presentation Factor
L_{pbm}	Measured Background Sound Pressure
L_{pf}	Fan Sound Pressure Level
L_{pfm}	Measured Sound Pressure Level of FAN +BKG
L_{pr}	RSS Sound Pressure Level
L_{prm}	Measured Sound Pressure Level of RSS + BKG
L_{wf}	Fan Sound Power Level
L_{wr}	RSS Sound Power Calibration
HVI	Home Ventilation Institute
HVAC	Heating Ventilation and Air Conditioning
R^2	Coefficient of Determination
REEL	RELLIS Energy Efficiency Laboratory
RCR	Room Characteristic Ratio
RPM	Revolutions per Minute
RSS	Resonant Sound Source
S	Final Sound Value
s_{max}	Critical Sone Value

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1. INTRODUCTION

HVI has been rating ventilation products and testing loudness at Texas A&M since 1970 [1]. The testing has continued to advance through the years and the introduction of new technologies has prompted the discussion to determine the differences, if any, of new equipment to the existing sound testing facilities. The purpose of this work is to determine the effects, if any, on the overall sones recorded when varying the testing equipment. The effect will be evaluated using different microphones, resonant sound sources (RSS), analyzers, and environmental conditions.

The Home Ventilating Institute (HVI) publishes a sound loudness testing and rating procedure, HVI 915 [1]. This standard rates residential ventilation product, such as bathroom fans, range hoods, and other fans in sones. A sone is a measurement of sound loudness, as the human ear perceives it. For the purpose of this study, sones are to be calculated using one-third octave measurements within a diffuse reverberant chamber. These measurements will be in accordance with the procedure described in HVI 915 [1]. A detailed explanation of sones is described later in this text

1.1 Objectives

The objective of this study is to use existing standards and procedures to determine the differences, if any, of new testing equipment on the overall value of sones measured. This study specifically focuses on microphone types and RSS types and their influences on sones measured. The objectives of this study and a brief explanation for each are as follows:

- Diffuse and Free Field Microphone Measurement Differences: Investigate the potential differences between two microphones and their effects on sone measurements.
- Resonant Sound Source Comparison: Investigate two resonant sound sources and their influence on sone measurements.

1.2 Scope

The study will be able to tell us if there are any differences in sones measured using new equipment that is compliant with the pre-existing testing procedures and standards for residential ventilation products. The residential ventilation products in the study will be limited to bathroom fans and range hoods exhibiting a wide range of sones. The sones will range from less than 0.3 sones to 11.5 sones. It is important to note that most residential fans are rated at 6 sones or less.

2. BACKGROUND

The ventilation industry uses a sone as a measure of how loud a residential ventilation device is perceived by the user. Common residential products in homes that are rated using sones include bathroom fans and range-hoods. Typically 28 dB is approximated as 1 sone. To put into perspective what a sone sounds like: 1.0 sones is the sound of a refrigerator, 3.0 sones is normal office noise, and 0.5 sones is the sound of leaves blowing in the wind [8].

The human hear perceives sound through fluctuations in sound pressure waves [10]. Due to the nonlinearity of sound, the human ear responds to small amplitudes more efficiently than large ones [10]. The ear senses pressure waves in a nonlinear scale and is described by the sound intensity level, otherwise known as, decibel level. It is defined by Equation 1 below.

$$D = 10\log(\frac{I}{I_O}) \tag{1}$$

Where,

D = decibel level [dB]

I = arbitrary wave of sound intensity [W/m^2]

I_0 = reference intensity corresponding to a level of 0 dB [W/m^2]

Note, that I_0 is approximately equal to the intensity of 1000 Hz at the threshold of hearing [10]. Traditionally decibels, dB, are used as a unit to express the relative intensity of sound. The unit, dB, is based on powers of 10 to give a range of numbers that contains the human hearing spectrum [10]. Although decibels cover the human hearing spectrum, they do not accurately reflect sound as it is perceived by the human ear, as human hearing can be more sensitive to specific frequencies.

The current HVI loudness rating procedure, specifically loudness rating, is based on the work of Stanley Smith Stevens and is known as the Conventional Model [3]. Stevens developed the sone unit for quantifying loudness in 1936, suggesting loudness predictions by using power law and equal loudness contours [3]. Stevens proposed the sone as a unit of measurement that scales sound as perceived by the human ear. To implement the psychological aspect of sound perception Stevens used equal loudness curves and applied them to sound power levels to weigh them before calculating a final sone value [9].

In addition, the current loudness procedure used by HVI uses a resonant sound source (RSS). HVI loudness testing procedure is based on ISO 6926, which defines the requirements for the sound performance and calibration for resonant sound sources [9]. This standard provides parameters for RSS spectral characteristics, directivity, and steadiness.

2.1 Motivation

This study is important because it shows potential differences in equipment and technologies. Specifically, it will look at if there are differences between diffuse and free field microphones and their application to sound testing residential ventilation products. The current testing procedure, HVI 915, requires a diffuse-field microphone. The results of this study will determine if a free-field microphone can be used for the same application and yield the same results.

HVI has publicized tolerances for the current testing procedure in HVI 920 to account for variances in sound testing values for a fan. HVI 920 currently states that the sound rating tolerance is no more than 110% of the sound rating plus 0.25 sones [6]. The data collected and analyzed for this study will help determine if the current HVI tolerances are appropriate and within a reasonable range.

The RELLIS Energy Efficiency Laboratory (REEL) at Texas A&M has a semi-reverberant sound facility that is qualified to do sound testing for HVI and Energy Star. This study was performed using this actual test facility, so the results will help demonstrate that the facility is qualified and produces correct and consistent results. This is important to REEL because companies within industry come and use the facilities to perform certification testing. These customers, as well as the consumers of their products, may come to question the results of these tests. Performing this study and confirming test results within the specified HVI tolerances, will act as evidence that REEL complies with all required standards and practices.

3. TESTING APPARATUS

The data collected and analyzed for this paper uses a semi-reverberant sound test chamber and facilities at RELLIS Energy Efficiency Laboratory (REEL) that complies with HVI 915 and ANSI S12.51 [2]. A detailed schematic of the major components of the semi-reverberant chamber is in Figure 1.

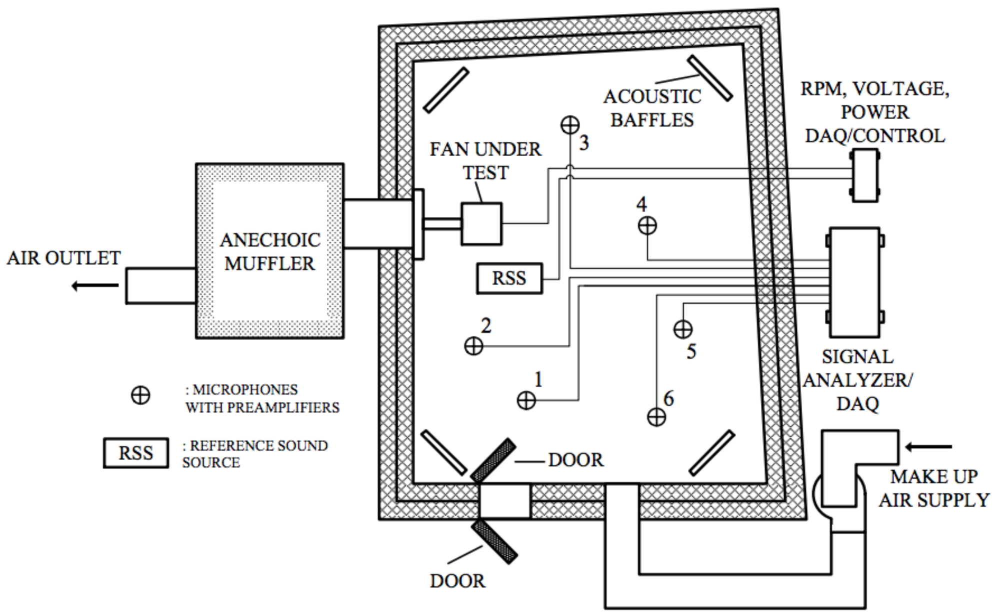

Figure 1: Schematic of Semi-Reverberant Sound Room. “Reprinted from A Transformative Investigation of Acoustical Testing Protocols for Residential Ventilation Devices” [3]

Since the room is semi-reverberant, this means that the surfaces in the room reflect all acoustic energy that is incident on the surface. As per the standard, the walls are non-parallel to obtain uniform reverberation over all surfaces [3]. The chamber is made with multi-layer insulating walls to reduce noise transmissions throughout the structure and remove unwanted infiltration of the room [3]. There are acoustic baffles in each of the four corners of the room, which act to minimize three-dimensional standing waves [3]. The inlet to the chamber is connected to an insulated duct that is equipped with a blower. The blower acts as a throttling device to adjust the static pressure and volumetric flow of a fan during each test [3]. The chamber outlet connects to an anechoic muffler that impedes the entrance of external noise into the chamber. There are six random incident microphones and preamplifiers placed inside the chamber and their placement corresponds to Annex C of ANSI S12.51. ANSI S12.51 is the standard that defines the room qualification procedure for microphone placement. There is a RSS inside the chamber used to generate broadband flat and loud noise spectrum along with calibrated sound power levels.

During each test, the following test conditions are monitored using control software and data acquisition devices: chamber temperature and humidity, the temperature and humidity outside of the chamber, atmospheric pressure, fan RPMs and fan static pressure. A list of relevant instruments and devices used for testing are located in Table 1. It is important to note that all instruments maintain up-to-date calibrations so that the uncertainty of the sound data can be determined.

Table 1: Sound Test Equipment and Uncertainties

Device	MFG/ Model No.	Measuring Quantity/Purpose	Range/Uncertainty
Free-field Microphone and Preamplifier (6 total)	Bruel & Kjaer 4190-L-001/Bruel & Kjaer 4942-L-001	Measure sound pressure levels in dB	14.6 – 146 dB 3.15 – 20000 Hz
Diffuse-field Microphone and Preamplifier (6 total)	Bruel & Kjaer 4942-L-001/Preamplifier Type 2669L	Measure sound pressure levels in dB	14.6 – 146 dB 6.3 – 16000 Hz
Pulse Multi-channel Data Analyzer	Bruel & Kjaer 3560C	Sound analyzer	N/A
Pulse Multi-channel Data Analyzer	Bruel & Kjaer	Sound analyzer	N/A
Acoustical Calibrator	Bruel & Kjaer 4231	Calibrate microphones and preamplifiers	94 dB ± 0.2 dB
RSS	ILG	Resonant sound source for measurements	N/A
RSS	Bruel & Kjaer 4204	Resonant sound source for measurements	N/A
Digital Panel Tachometer	Monarch ACT-3	Measure fan RPM	5 – 999990 RPM/ ±0.5 RPM
Multimeter	FLUKE 87V	Measure and monitor voltage for fan and RSS	0 – 1000 V/ ± 1.04 V

3.1 HVI Testing Procedure and Calculations

The sound pressure levels of a fan within the semi-reverberant room are measured in accordance to the procedure outlined in HVI 915. Before each test, the unit must warm up for at least 30 minutes or until it reaches stable operating conditions, whichever is longer [1]. Once the fan is mounted inside the chamber, the static pressure must be matched to the airflow test. This is done by adjusting the inlet air, discharge air or both [1]. Once the testing conditions are satisfied the sound test can begin. Each sound test has four sound measurements associated with it: the unit, the first background, RSS, and the second background; it follows the following four steps:

1. Test unit operating at the same static pressure as the airflow test, $L_{pfm} + L_{pbm}$. This is the fan and background sound pressure measurement [UNIT + BKG].
2. Background sound pressure level, L_{pbm}. The unit is turned off [BKG1].
3. RSS turned on and background sound pressure level, $L_{prm} + L_{pbm}$, [RSS + BKG].
4. Background sound pressure level with the RSS turned off, L_{pbck} [BKG2].

During the test, each of the measurements mentioned above measurement takes 30 seconds. The data comes from a signal analyzer that real-time signal processes the time-domain sound pressure measurements into 24 1/3 octave band frequencies from 50 to 10,000 Hz [3]. After completing all four measurements for a test, the backgrounds are to be compared, namely BKG1 and BKG2, to determine background steadiness. There are background steadiness limits defined in HVI 915. For example, if the limit of the 500 Hz band is 1 dB and the arithmetic difference between BKG1 and BKG2 is less than the limit (1 dB), then background steadiness is achieved at the 500 Hz band. Assuming that the background of a test is steady and quiet for all bands, then the data can be processed to calculate the final sone value.

The measured data from the test undergoes a series of conversions to a loudness index. The fan sound pressure levels, L_{pf}, are calculated by logarithmically subtracting measured background sound pressure, L_{pbm}, from the measured sound pressure of FAN + BKG, L_{pfm} [1]. The equation to find the fan sound pressure level is in Equation 2 below.

$$L_{pf} = 10Log_{10}(10^{\frac{L_{pfm}}{10}} - 10^{\frac{L_{pbm}}{10}}) \tag{2}$$

RSS sound pressure, L_{pr}, is then calculated by logarithmically subtracting measured background sound pressure level, L_{pbm}, from measured sound pressure level of RSS + BKG, L_{prm} [1]. The equation to find RSS sound pressure is presented in Equation 3.

$$L_{pr} = 10Log_{10}(10^{\frac{L_{prm}}{10}} - 10^{\frac{L_{pbm}}{10}}) \tag{3}$$

Next the room characteristic ratio, RCR is calculated by arithmetically subtracting RSS sound pressure, L_{pr}, from the RSS sound power calibration, L_{wr} [1]. The RCR is the ratio of RSS sound power divided by RSS sound pressure [1]. The equation to find the RCR is in Equation 4.

$$RCR = L_{wr} - L_{pr} \tag{4}$$

The fan sound power, L_{wf}, is calculated by arithmetically adding the RCR to the fan sound pressure, L_{pf} [1]. The equation for fan sound power is in Equation 5.

$$L_{wf} = L_{pf} + RCR \tag{5}$$

The fan sound pressure for the environment, L_{pf}' is calculated by converting the sound pressure levels in a spherical free-field at a distance of 5fr (1.52 m) from the fan under test [1]. This value, called the presentation factor, K, is 14.65 dB and is subtracted from the sound power. This is the last step before the HVI equal loudness index tables are used. The equation for the sound power for the environment is in Equation 6.

$$L'_{pf} = L'_{wf} - 14.65\ dB \tag{6}$$

Loudness at each band is obtained by looking up loudness at the corresponding band frequency for the converted sound pressure [3]. The HVI equal loudness indices are weighted for human response to dominant tones as a function of sound pressure levels and one-third octave band frequencies [3]. The final sone rating, which is a single sone value, S, is calculated by adding 85 percent of the maximum loudness at the most dominant band (in sones) and then adding 15 percent of the sum of the other 23 loudness values as defined in HVI 915 [1]. The final sone value is located in Equation 7.

$$S = 0.85s_{max} + 0.15(s_1 + s_2 + \cdots + s_{23} + s_{24}) \tag{7}$$

A sample test report that is from a bathroom fan tested for HVI is located in Appendix A.

4. METHODOLOGY

4.1 Microphone Influence on Sones

A study has been performed to focus on the difference between two microphones: free field and diffuse. The current standard, HVI 915, requires “random incident microphones having a linear free field response” [1]. Two microphone types, free field and diffuse, are to be compared because the wording in HVI 915 paragraph 4.7 is ambiguous, a microphone cannot be both diffuse and free field because that is a description of their frequency response to sound pressure levels.

A free field microphone has uniform frequency response for the sound pressure that existed before the microphone was introduced to the environment [7]. Any microphone placed into an environment will disturb it, however, the free field microphone is designed to account for its presence and correct itself. Free field microphones are used in applications were sound is coming from one direction. A diffuse field microphone is designed to respond uniformly to sound pressures coming from all angles. It is recommended that diffuse field microphones are to be used in reverberant rooms but also in outdoor situations where the sound is reflected off objects such as walls. This is due to the fact that diffuse microphones work best where the sound field is a diffuse field (i.e. coming from all angles) [7].

Both microphones, free-field and diffuse, will be used in the semi-reverberant sound room at REEL. Comparing these microphone types will show if they yield differences in sone values.

4.2 RSS Influence on Sones

A study has been performed on RSS data at REEL using the semi-reverberant sound facilities to investigate the effects on the sones recorded using different RSS. The two resonant sound sources used were from Bruel and Kjaer Sound and Vibration (B&K) and ILG Electric Ventilation Co. (ILG). Both RSS devices are approved for use by HVI, the only difference between them is that B&K is newer. These two RSS devices were analyzed and compared through a series of trials for a total of 48 sound tests. These trials were grouped together appropriately by the RSS type to analyze the results on sones recorded. It is important to note that this study used diffuse field microphones. Additional analysis on the influence of an RSS on sones is evaluated in 4.3. Testing Procedure for RSS and Microphone Influences on Sones

To determine if there are any differences in equipment changes to the semi-reverberant room at the REEL sound facility an experiment was designed to investigate the effects, if any, on the overall sone value of residential ventilation devices tested. There are two groups of microphones: free-field and diffuse. In addition, there are two groups of resonant sound sources (RSS): B&K and ILG. Each group of microphones and RSS devices will be set up according to the standard testing procedure in HVI 915.

There were eight residential ventilation devices, ranging from less than 0.3 sones to 11.5 sones. These units consisted of both range-hoods and bathrooms in order to supply a wide range of data. The units used and their sound rating are located in Table 2. The lower sone units are bathroom fans and the higher sone units are rangehoods.

Table 2: Units used for Sound Trials

Rated Sones	Model	Classification
<0.3	FV-05-11VFM5 (2 speed – 80 CFM)	Bathroom Fan
~1	FV-05-11VFM5 (2 speed – 110 CFM)	Bathroom Fan
2.5	HD80L	Bathroom Fan
5.5	QSE130BL	Rangehood
6	Qingdao Rangehood	Rangehood
8	WA0876	Rangehood
10	HCB36-6	Rangehood
11.5	SEV24S	Rangehood

The units in Table 2 are tested as follows:

- Each unit was mounted according to HVI 915
- Tests were ran for both microphones and both RSS devices as follows:
  - Diffuse Microphone
    - B&K RSS (3 runs)
    - ILG RSS(3 runs)
  - Free-field Microphone
    - B&K RSS (3 runs)
    - ILG RSS (3 runs)
- Fan was left mounted to remove any differences from mounting

Each unit was tested a total of 12 times, resulting in 96 sound tests. The results from these trials are used in subsequent sections to analyze both the microphone comparison and RSS comparisons.

5. RESULTS

5.1 Microphone Influence on Sones

An analysis of the data gathered for different microphone types, free-field and diffuse, will be discussed in this section. The microphone types will be analyzed with both the B&K and ILG RSS devices.

5.1.1 Microphone Influence on Sones using ILG RSS

The results of the 8 different fans with their trials using the free-field and diffuse microphones while using the ILG RSS are presented in Table 3. These trials were conducted using the procedure discussed in the previous sections of the text. The mean shows the arithmetic average of the sone values from the trials. The standard deviation shows the amount of dispersion within the data set for each unit. The coefficient of variation is a measure of relative variability – it is the standard deviation divided by the average. Lastly, the range is presented for each fan type (min minus max) with minimum and maximum values of the data set shown as well. In general, the range and standard deviation of sone values increases as the sone rating increases. For example, the standard deviation and range at less than 0.3 sones for the diffuse field microphone is 0.004 and 0.008, respectively. The standard deviation and range at 8 sones for the diffuse field microphone is 0.281 and 0.500.

Table 3: Data from trails using ILG RSS for Free-Field and Diffuse Microphones

Sone Rating	Mic Type	Average	Std Dev	Min	Max	Coefficient of Variation	Range
>0.3	**Free-field**	0.275	0.002	0.273	0.277	0.76%	0.004
	Diffuse	0.271	0.004	0.268	0.276	1.61%	0.008
~1	**Free-field**	0.862	0.009	0.852	0.869	1.01%	0.017
	Diffuse	0.849	0.002	0.847	0.850	0.18%	0.003
2.5	**Free-field**	2.579	0.022	2.560	2.604	0.87%	0.044
	Diffuse	2.559	0.013	2.546	2.571	0.49%	0.025
5.5	**Free-field**	5.334	0.005	5.329	5.339	0.09%	0.010
	Diffuse	5.333	0.023	5.315	5.359	0.43%	0.044
6	**Free-field**	6.645	0.015	6.636	6.662	0.23%	0.026
	Diffuse	6.795	0.033	6.757	6.820	0.49%	0.063
8	**Free-field**	8.226	0.029	8.204	8.259	0.36%	0.055
	Diffuse	8.131	0.281	7.807	8.307	3.46%	0.500
10	**Free-field**	9.614	0.020	9.596	9.636	0.21%	0.040
	Diffuse	9.457	0.095	9.399	9.566	1.00%	0.167
11.5	**Free-field**	12.063	0.094	11.957	12.136	0.78%	0.179
	Diffuse	12.401	0.043	12.372	12.451	0.35%	0.079

The average sones measured versus the rated sones measured for the free-field and diffuse microphones using the data is presented in Table 3 and plotted in Figure 2. The error bars represent one standard deviation of the sample. Additionally, the R^2 values for a linear trend line for the microphones is included. R^2, otherwise known as the coefficient of determination, is a statistical measure of how close the data is for a fitted regression line. Generally speaking, the closer an R^2 value is to 1 means that the line is a good fit. The R^2 value for a linear trend-line for the free-field microphone is 0.9934 and is 0.9881 for the diffuse microphone. Since both these values are close to 1, it is appropriate to suggest that the average values for both microphones correlate with their rated sones. Figure 2 helps illustrate that the average values for both microphones correlate with their rated sone values.

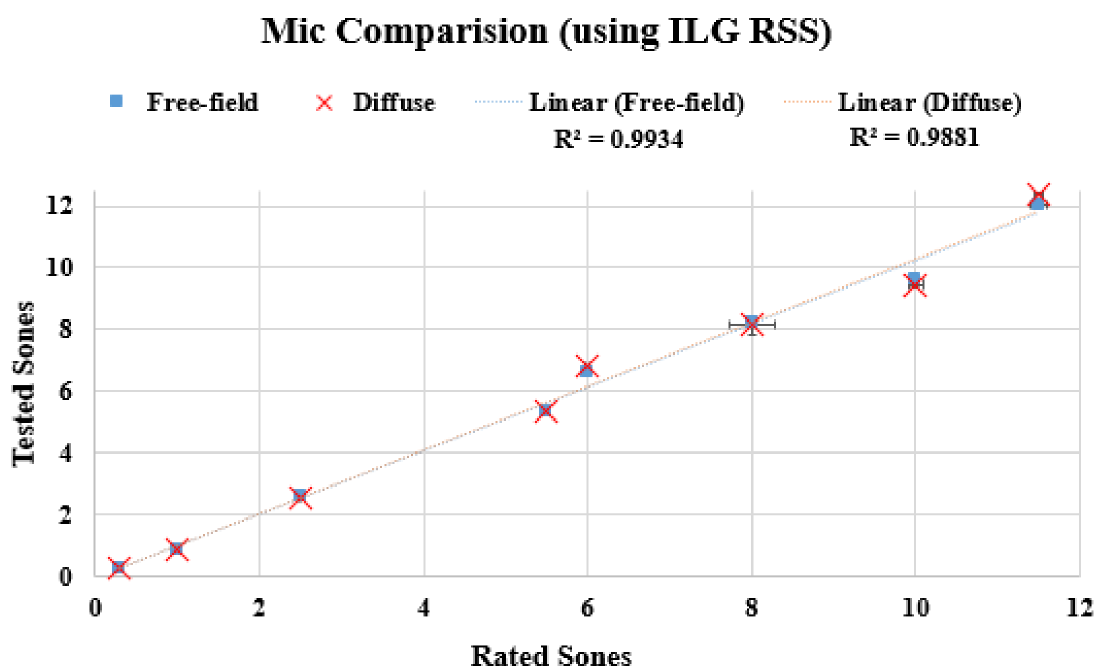

Figure 2: Microphone Comparison using ILG RSS

Using the same data presented in Table 3, the average change in sones for each fan group was calculated by averaging the change in sones between the two microphone types (free-field and diffuse). The data was further used to calculate the absolute average of the change in sones between the microphone types. The absolute average takes the absolute value of the average change in sones for each fan group. Finally, the average change in sones was calculated as a percentage of the sound rating for that fan group. The data is presented in Table 4. Looking at the data in Table 4, the sone rating increases, the absolute average change in sones between the microphones increases. To gather more information from the data presented in Table 4, plots were generated to give a qualitative view.

Table 4: Average Change in Sones for ILG RSS

Sone Rating	Mic Type	Average	Avg Δ Sones	Abs Avg Δ Sones	Change in sones relative to rating
>0.3	**Free-field**	0.275	0.004	0.006	1.57%
	Diffuse	0.271			
~1	**Free-field**	0.862	0.013	0.013	1.51%
	Diffuse	0.849			
2.5	**Free-field**	2.579	0.020	0.020	0.78%
	Diffuse	2.559			
5.5	**Free-field**	5.334	0.001	0.014	0.01%
	Diffuse	5.333			
6	**Free-field**	6.645	-0.150	0.150	2.26%
	Diffuse	6.795			
8	**Free-field**	8.226	0.095	0.170	1.15%
	Diffuse	8.131			
10	**Free-field**	9.614	0.158	0.158	1.64%
	Diffuse	9.457			
11.5	**Free-field**	12.063	-0.338	0.338	2.80%
	Diffuse	12.401			

Referring to Table 4, the average difference is plotted against the rated sones in Figure 3. The plot of the average difference versus the rate sones shows that as the rated sones increase so does the average change in sones. However there is no clear trend, as values fluctuate between positive and negative values. For example, the fan at 10 sones has an average change in sones of 0.158 and the fan at 11.5 sones has an average change in sones of -0.338. Since the values are neither consistently positive nor negative, it is reasonable to assume that one microphone does not read higher than the other does.

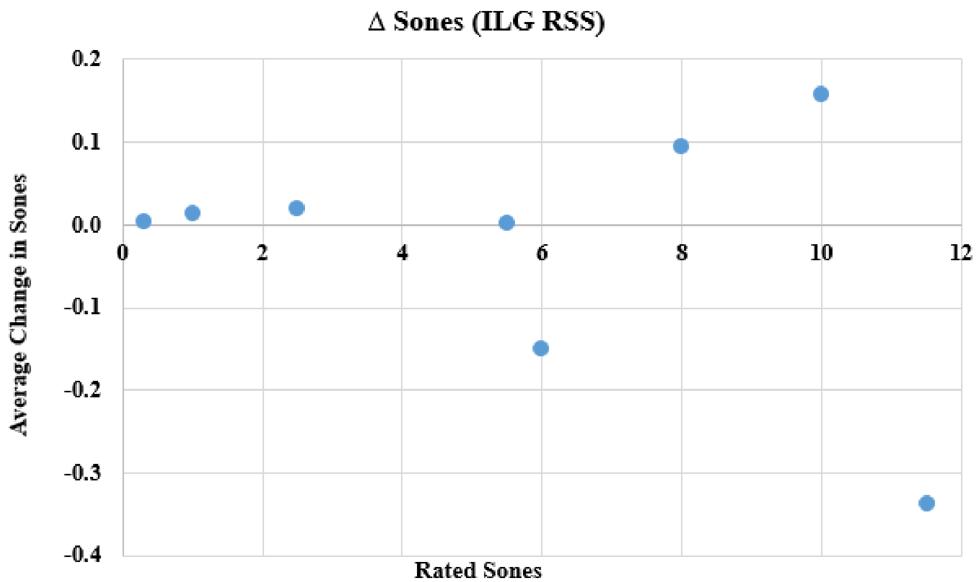

Figure 3: Average Change in Sones using ILG RSS

The absolute average difference between the sones measured between each microphone is plotted in Figure 4. The plot shows a roughly exponential trend in the difference in sones between the two microphones. As the rated sones increase so does the change in sones. This is significant because it illustrates that as the sones of a fan increase, the difference between the measured values increases with the different microphone types. Therefore, there may not be an effect at lower sones, but higher sones may be influenced. It is important to remember that this reflects the absolute change and does not show that the negative values of the changes. An exponential trend line was applied to the rated sones absolute average change in sones versus to establish an exponential trend. The coefficient of determination, R^2, is 0.8219 which suggests a weak exponential trend and is insignificant.

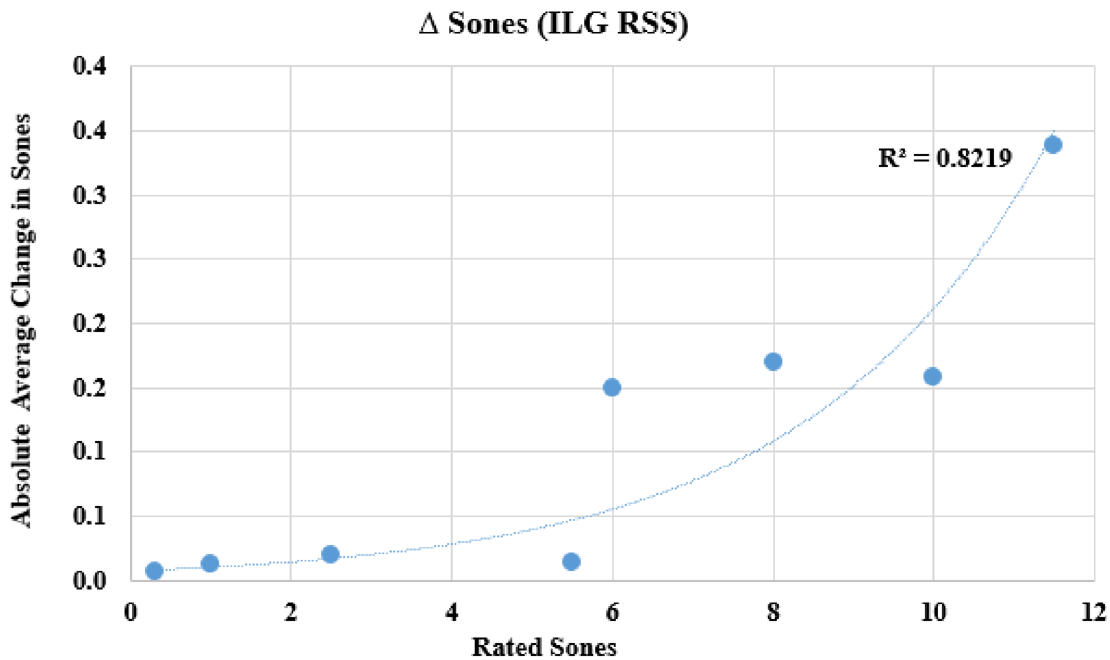

Figure 4: Absolute Average Change in Sones using ILG RSS

The average change in sones relative to the rated value is in Figure 5. It is important to note, that the values plotted are the absolute values as the data is being compared to a positive set value. From Figure 5, there does not seem to be any correlation between the relative change in sones and the rated values. The data points are scattered and do not show the same behavior for the range of sones tested. In order to improve this discrepancy more trials would need to be run and evaluated.

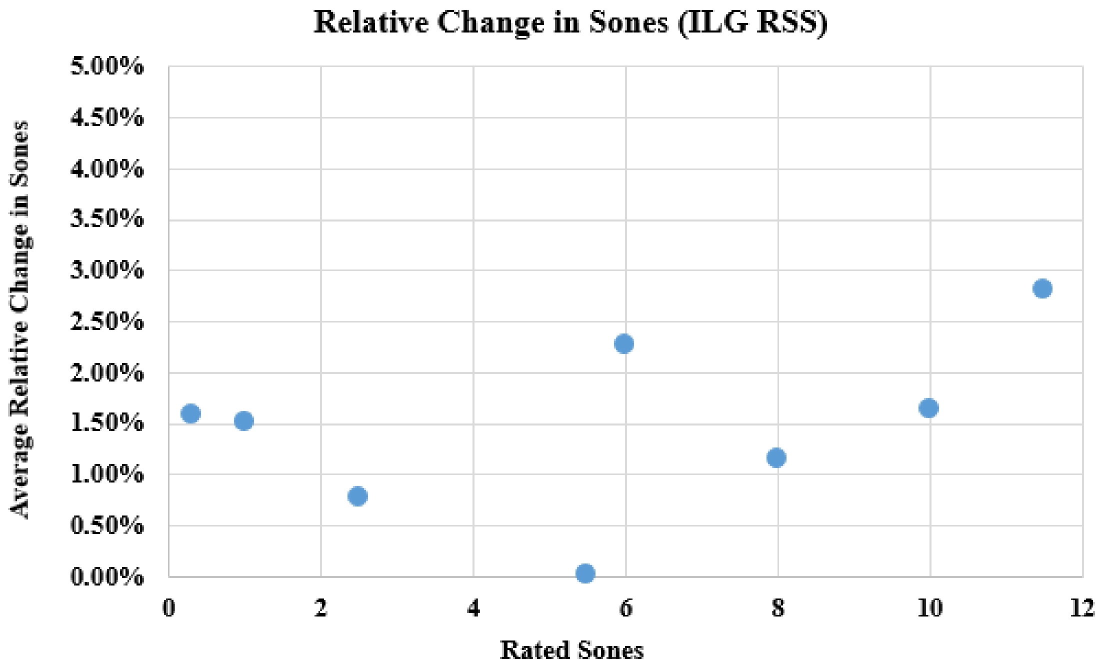

Figure 5: Relative Change in Sones as a Percentage of the Rated Value

From all the tests analyzed, the weak or lack of correlation between the free-field and diffuse field microphone while using the ILG RSS show that the sones recorded are not noticeably influenced by any specific microphone.

5.1.2 Microphone Influence on Sones using B&K RSS

The results of the 8 different fans with their trials using the free-field and diffuse microphones with the B&K RSS are presented in Table 5. These trials were conducted using the procedure discussed in the previous sections of the text. Similar to the ILG RSS, the range and standard deviation of sone values using the B&K RSS increases as the sone rating increases. For example, the standard deviation and range at 2.5 sones for the diffuse field microphone is 0.016 and 0.030, respectively. The standard deviation and range at 11.5 sones for the diffuse field microphone is 0.036 and 0.070.

Table 5: Data from Trails using B&K RSS for Free-Field and Diffuse Microphones

Sone Rating	Mic Type	Average	Std Dev	Min	Max	Coefficient of Variation	Range
>0.3	**Free-field**	0.279	0.010	0.268	0.288	3.64%	0.020
	Diffuse	0.277	0.005	0.273	0.283	1.91%	0.010
~1	**Free-field**	0.823	0.004	0.821	0.828	0.49%	0.007
	Diffuse	0.824	0.005	0.819	0.829	0.61%	0.010
2.5	**Free-field**	2.577	0.009	2.569	2.586	0.33%	0.017
	Diffuse	2.556	0.016	2.543	2.573	0.61%	0.030
5.5	**Free-field**	5.361	0.036	5.333	5.401	0.66%	0.068
	Diffuse	5.374	0.049	5.322	5.419	0.91%	0.097
6	**Free-field**	6.937	0.062	6.872	6.996	0.90%	0.124
	Diffuse	6.893	0.077	6.810	6.962	1.12%	0.152
8	**Free-field**	8.193	0.020	8.179	8.216	0.25%	0.037
	Diffuse	8.323	0.037	8.283	8.357	0.45%	0.074
10	**Free-field**	9.700	0.060	9.644	9.764	0.62%	0.120
	Diffuse	9.528	0.067	9.451	9.568	0.70%	0.117
11.5	**Free-field**	12.014	0.051	11.693	12.064	0.42%	0.101
	Diffuse	12.495	0.036	12.464	12.534	0.29%	0.070

The average sones measured versus the rated sones for each fan for both microphones using the data in Table 5 is plotted in Figure 6. There are error bars, which are too small to see, that represent one standard deviation of the sample. Additionally, the R^2 values for a linear trend line for the microphones is included. The R^2 value for a linear trend-line for the free-field microphone is 0.9914 and is 0.9877 for the diffuse microphone. These values are extremely close to 1, suggesting a strong linear trend between the average tested sones and the rated. Figure 6 helps illustrate that the values between the free-field and diffuse microphone are similar because they both follow a linear trend.

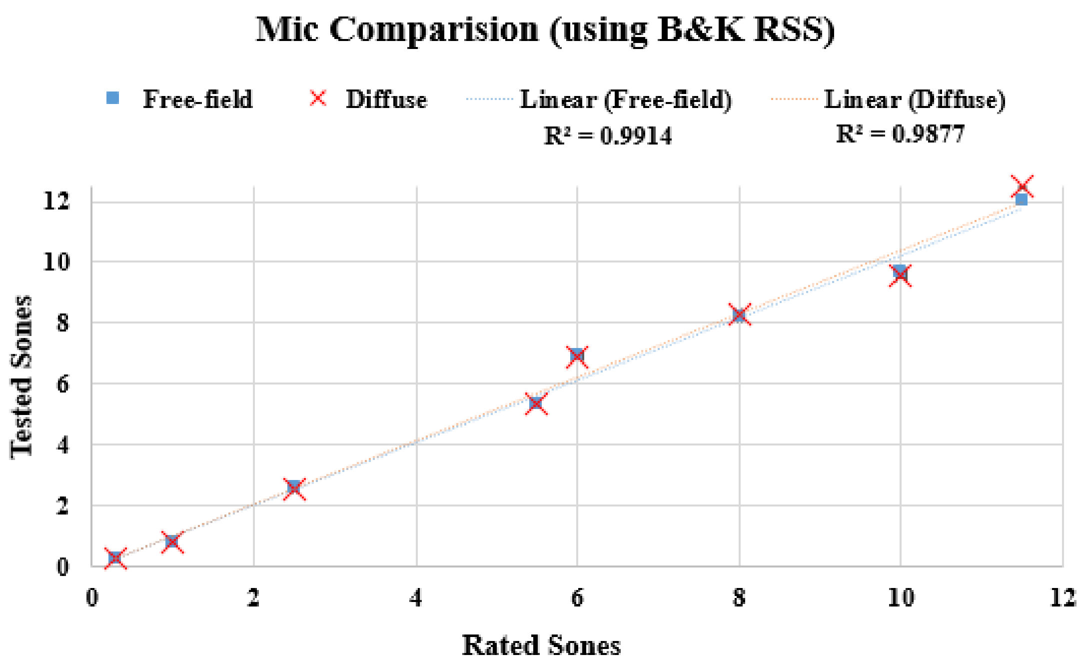

Figure 6: Microphone Comparison using B&K RSS

Using the same data presented in Table 5, the average change in sones for each fan group was calculated by averaging the change in sones between the two microphone types, free-field and diffuse. The data was additionally used to calculate the absolute average of the change in sones between the microphone types. The absolute average takes the absolute value of the average change in sones for each fan group. Finally, the average change in sones was calculated as a percentage of the sound rating for that fan group. The data is presented in Table 6. Looking at the data in Table 6, the average change in sones fluctuates between positive and negative values. For example, the unit at

1 sone has an average change in sones of -0.001 and at 6 sones there is a 0.044 average change in sones. The absolute average change in sones is increasing as the rating increases.

Table 6: Average Change in Sones using B&K RSS

Sone Rating	Mic Type	Average	Avg Δ Sones	Abs Avg Δ Sones	Change in sones relative to rating
>0.3	**Free-field**	0.279	0.002	0.005	0.72%
	Diffuse	0.277			
~1	**Free-field**	0.283	-0.001	0.002	0.08%
	Diffuse	0.284			
2.5	**Free-field**	2.577	0.021	0.021	0.82%
	Diffuse	2.556			
5.5	**Free-field**	5.361	-0.013	0.031	0.25%
	Diffuse	5.374			
6	**Free-field**	6.937	0.044	0.044	0.63%
	Diffuse	6.893			
8	**Free-field**	8.193	-0.013	0.130	1.59%
	Diffuse	8.323			
10	**Free-field**	9.700	0.171	0.171	1.77%
	Diffuse	9.528			
11.5	**Free-field**	12.014	-0.481	0.481	4.00%
	Diffuse	12.495			

To give a more quantitative view of the data in Table 6, Figure 7 was generated for the absolute average difference between the sones measured between each microphone. The plot of the average difference of sones versus the rated sones does not show a clear correlation because the values fluctuate between positive and negative values. For example, the average change in sones is -0.013 at 5.5 sones and is 0.044 at 6 sones. Therefore, there is no clear correlation between the average change in sones and the rated ones using the B&K RSS.

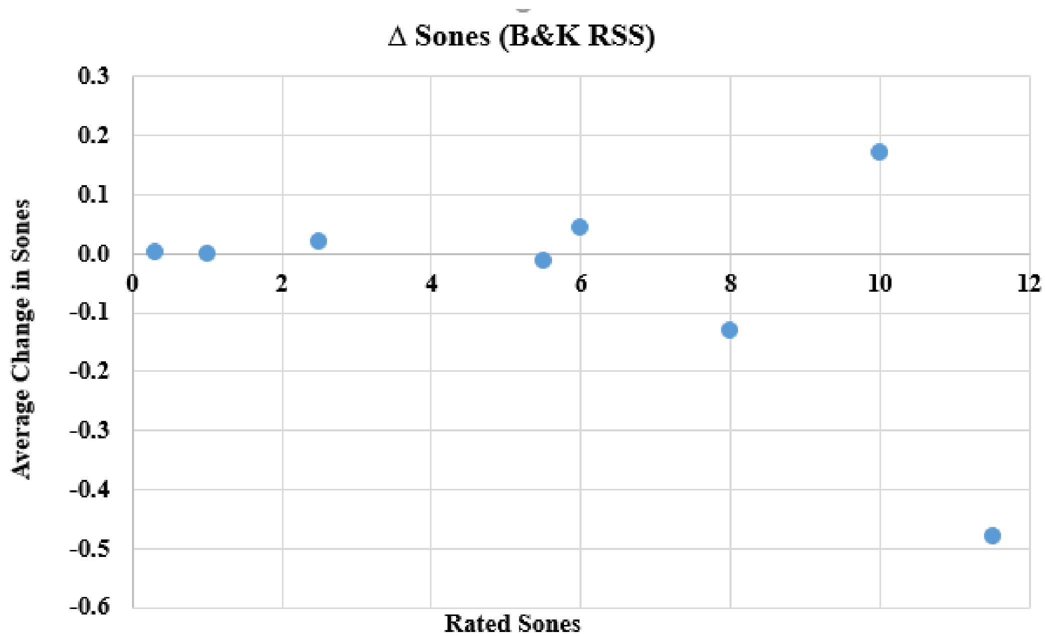

Figure 7: Average Change in Sones using B&K RSS

The absolute average change in sones versus the rated sones is plotted in Figure 8. The change in sones using the B&K RSS is similar to the change in sones using the ILG RSS. As the sones increase, the change in sones measured by the microphone increase. The trend appears to be exponential as well, suggesting that there may not be a noticeable difference in sones recorded at lower values but higher sones may be affected by using different microphone types. Additionally, an exponential trend line was added and it shows an R^2 values of 0.9232. This is not an extremely high coefficient of determination but it helps support that as the rated sones increase the absolute average change in sones does, affecting higher sone values.

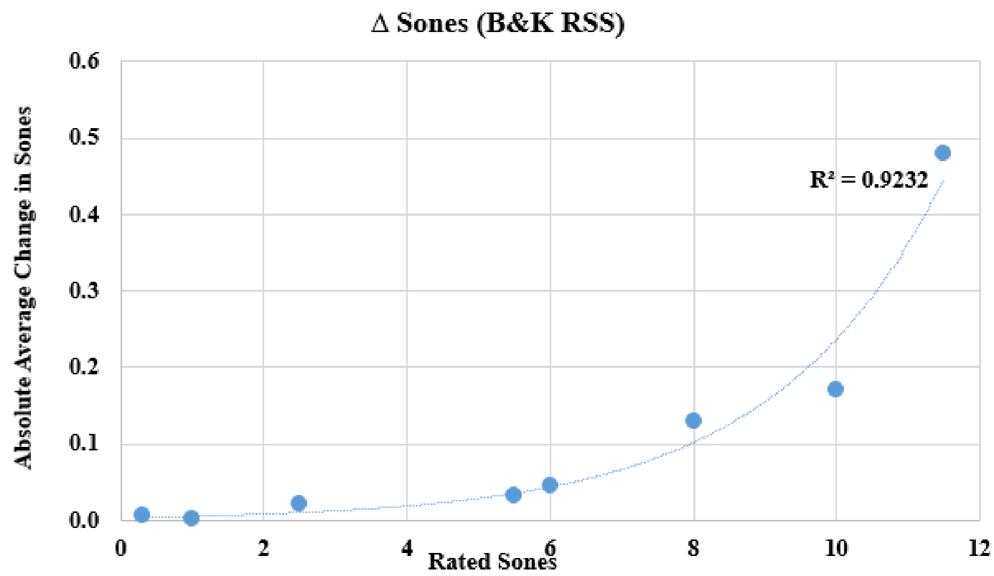

Figure 8: Absolute Average Change in Sones using B&K RSS

The average change in sones relative to the rated value is in Figure 9 and shows the relative change in sones as a percentage of the fan's rated value. There is no clear trend except for the relative change in sones tends to increase as the rated sones increase.

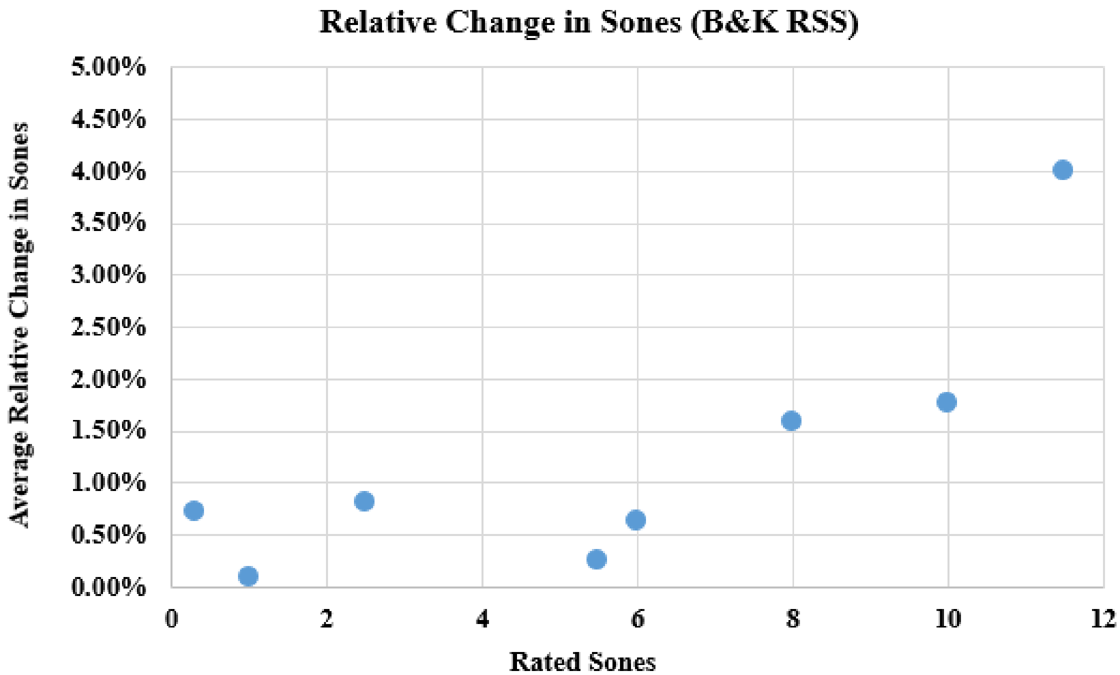

Figure 9: Relative Change in Sones using B&K RSS

From the data presented, there suggests a weak or nonexistent correlation between the sones measured using free-field and diffuse field microphones with the B&K RSS.

5.2 RSS Influence on Sones

Similar sound rooms designed according to the same standard can give different results on the sones measured. The average change of sones for varying residential ventilation devices using two different RSS devices, B&K and ILG, were analyzed. Eight different residential ventilation devices were tested three times using both the B&K and ILG RSS separately. During the testing the fans were ran with one RSS for all the trials, then after those trials were completed the next trails for the other RSS were run. This was done to prevent any changes in the mounting of the fan. The only change to the room was when the RSS were swapped. It is also important to note that the diffuse field microphones were used for all the data presented for these trials. This is because it is the equipment that the room is qualified for. The results for both the ILG and B&K RSS are below in Table 7 and Table 8.

Table 7: Data for ILG RSS Trials

Rated Sones	Average	Std Dev	Min	Max	Coefficient of Variation	Range
<0.3	0.277	0.005	0.273	0.283	1.91%	0.010
~1	0.824	0.005	0.819	0.829	0.61%	0.010
2.5	2.556	0.015	2.543	2.573	0.61%	0.030
5.5	5.374	0.049	5.322	5.419	0.91%	0.097
6	6.889	0.082	6.810	6.962	1.12%	0.152
8	8.323	0.037	8.283	8.357	0.45%	0.074
10	9.528	0.067	9.451	9.568	0.70%	0.117
11.5	12.495	0.036	12.464	12.534	0.29%	0.070

Table 8: Data for B&K RSS Trials

Rated Sones	Average	Std Dev	Min	Max	Coefficient of Variation	Range
<0.3	0.271	0.004	0.268	0.276	1.61%	0.008
~1	0.849	0.002	0.847	0.850	0.18%	0.003
2.5	2.559	0.013	2.546	2.571	0.49%	0.025
5.5	5.333	0.023	5.315	5.359	0.43%	0.044
6	6.795	0.033	6.757	6.820	0.49%	0.063
8	8.131	0.281	7.807	8.307	3.46%	0.500
10	9.457	0.095	9.399	9.566	1.00%	0.167
11.5	12.401	0.043	12.372	12.451	0.35%	0.079

From the data in Table 7 and Table 8 the average of the trials for each fan group is plotted in Figure 10. The error bars on the bar graphs represent one standard deviation. The graph above illustrates that the sones measured for the different sone ratings are similar in values. A preliminary look at Figure 10 shows that the values of all the fans seem to be within one standard deviation of each other but since the plot shows a wide data range without much detail, the individual sone groups are enlarged and can be seen in Figure 11 through 18. It is important to note that the only sone groups that do not fall within one standard deviation of each other are 1 sone and 11.5 sones. Since only two fans do not fall within one standard deviation it cannot be concluded that the sones recorded for the units are not within one standard deviation. More data would need to be gathered to determine if there is a relationship between the values of the B&K and ILG RSS and the sones measured.

Conclusively, there is not a correlation between the ILG and B&K RSS devices that suggests they produce different values for sound tests.

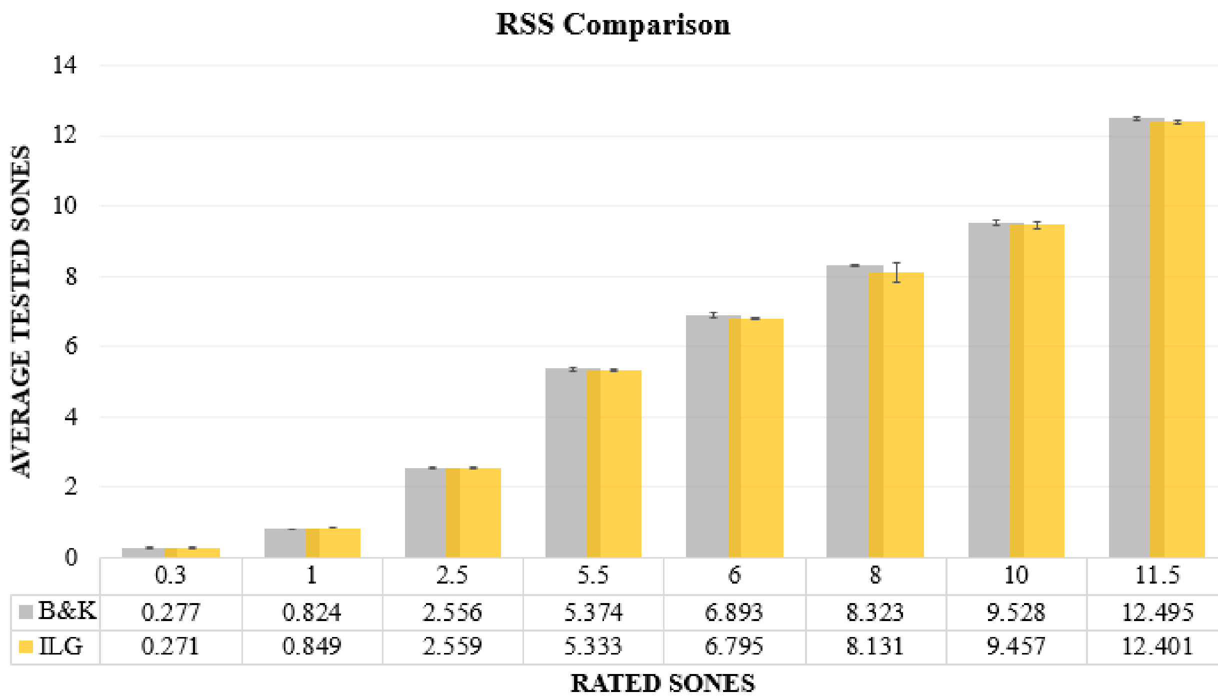

Figure 10: ILG vs. B&K RSS Comparison

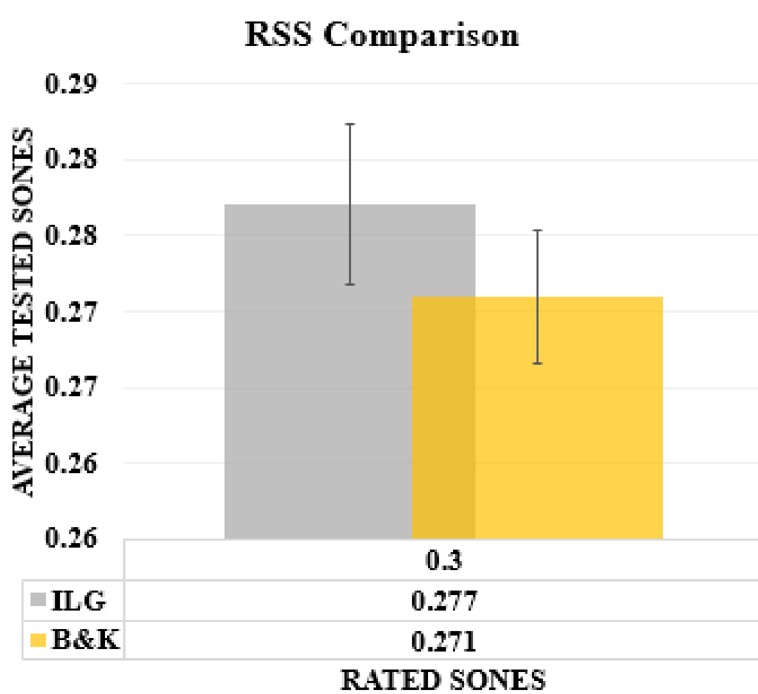

Figure 11: ILG vs. B&K Comparison - <0.3 sones

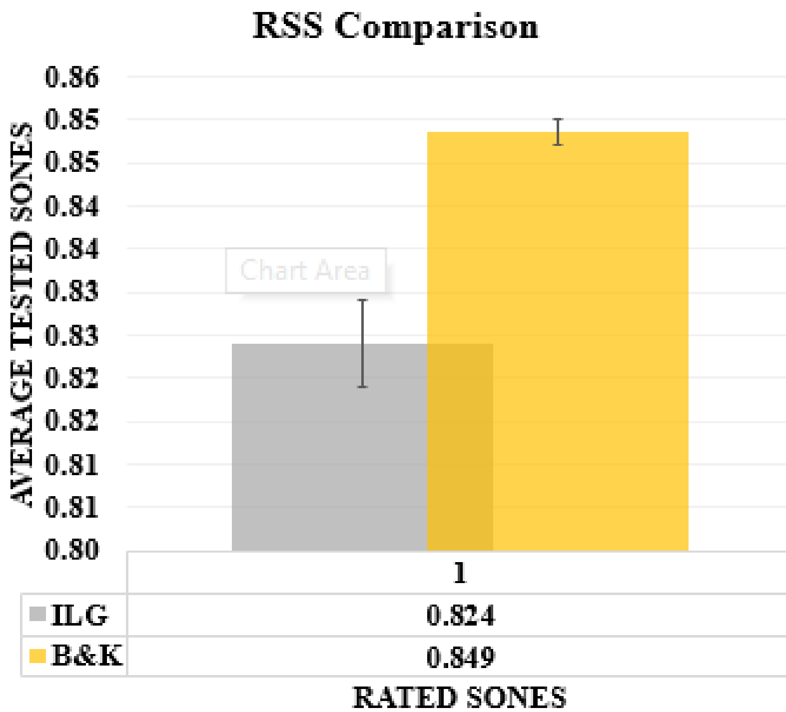

Figure 12: ILG vs. B&K Comparison - ~1 sone

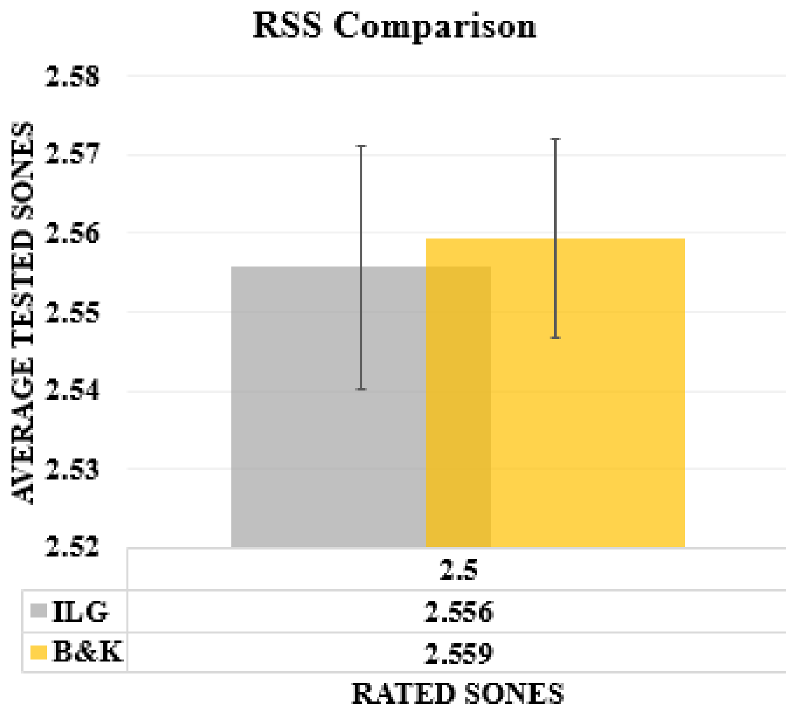

Figure 13: ILG vs. B&K Comparison - 2.5 sones

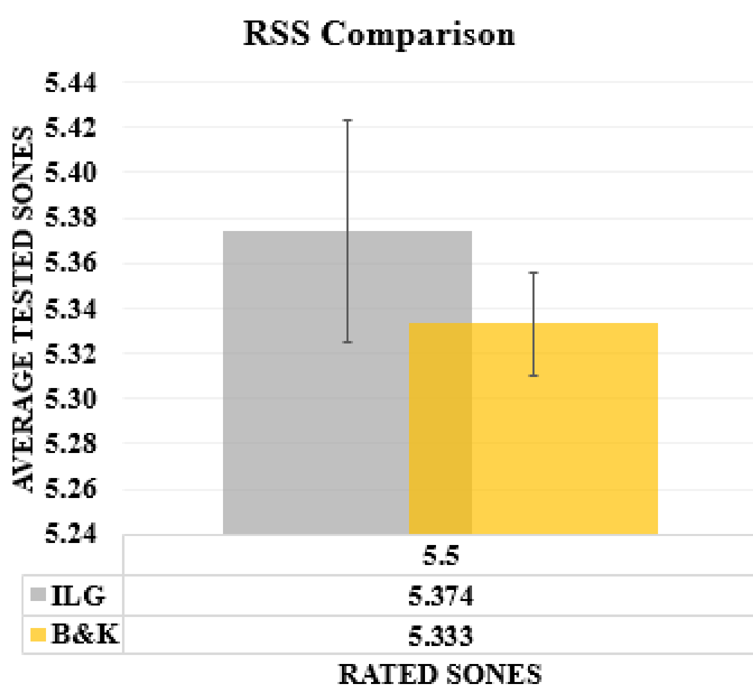

Figure 14: ILG vs. B&K Comparison - 5.5 sones

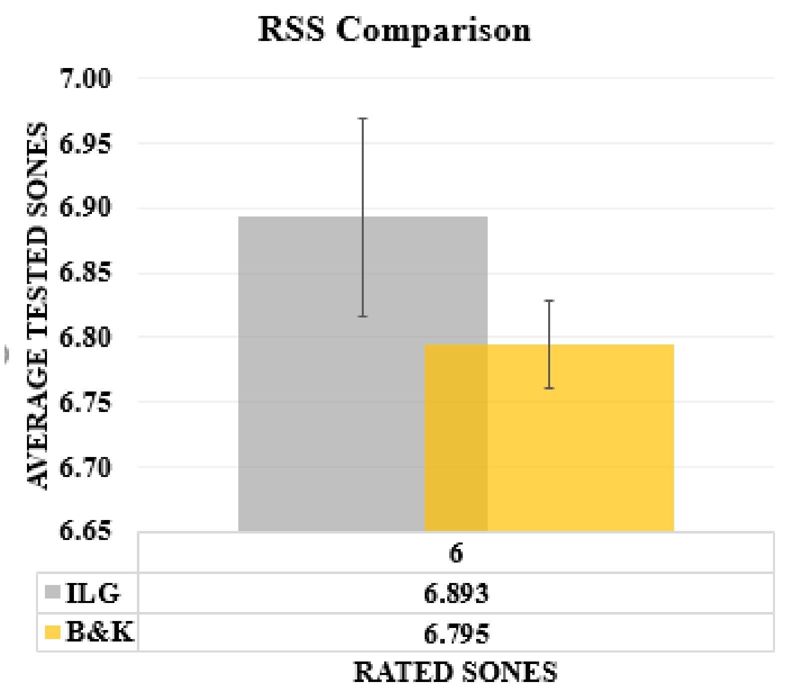

Figure 15: ILG vs. B&K Comparison - 6 sones

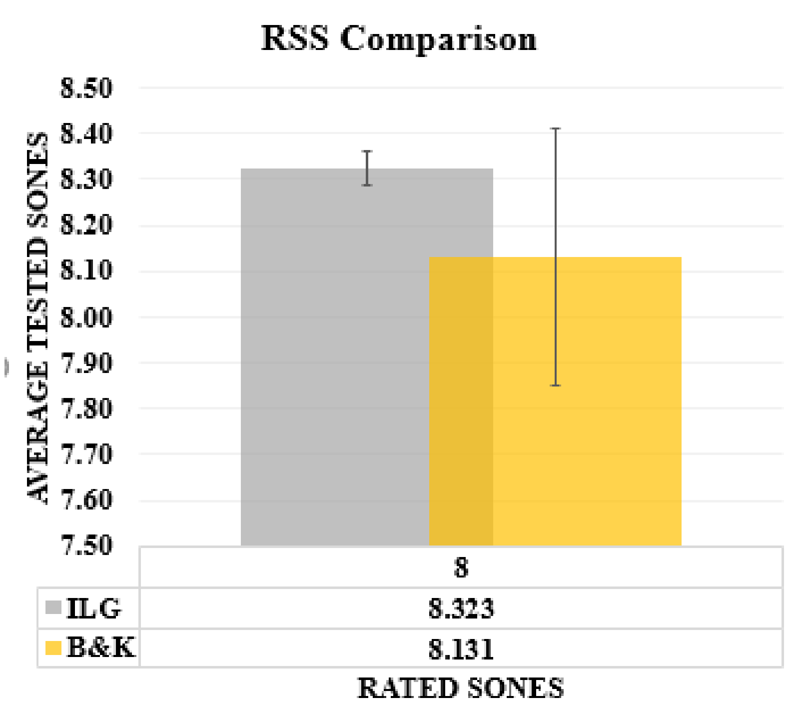

Figure 16: ILG vs. B&K Comparison - 8 sones

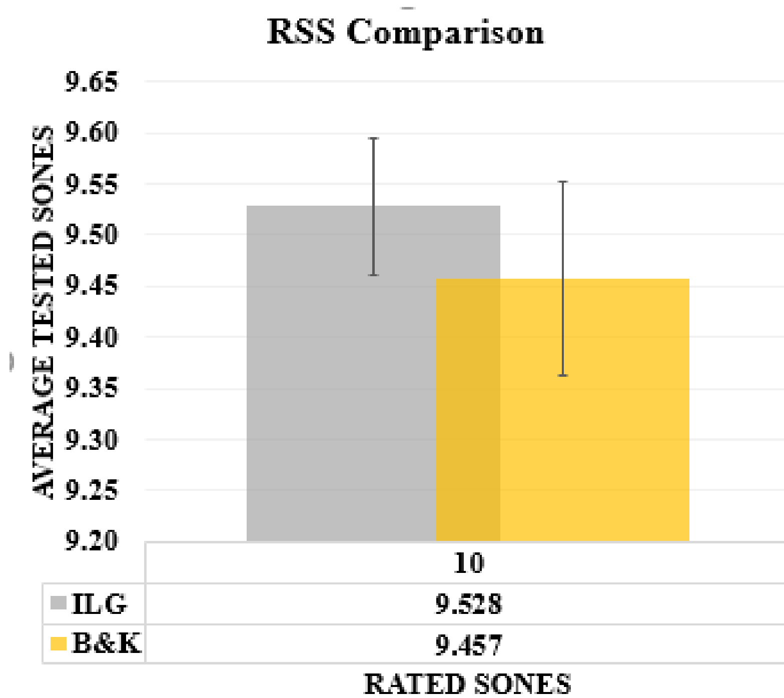

Figure 17: ILG vs. B&K Comparison - 10 sones

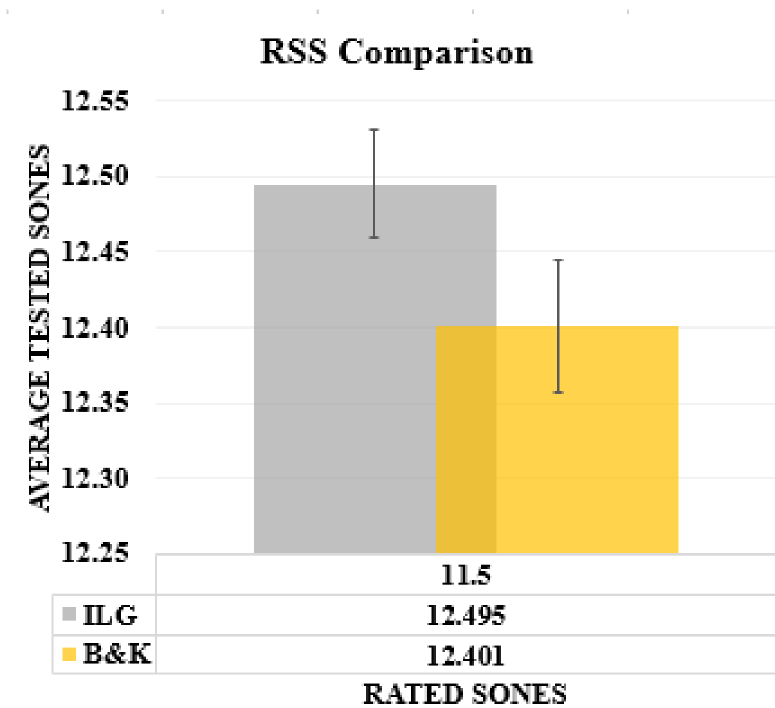

Figure 18: ILG vs. B&K Comparison - 11.5 sones

6. RECOMMENDATIONS FOR FUTURE STUDY

The results obtained thus far for the microphone comparison and RSS comparison could be further investigated to fully quantify the differences in the value of sones recorded. Specifically, additional trials need to be run for residential ventilation devices that are rated over 8 sones because this is where the difference in sones increases between the free-field and diffuse microphones. Additionally, more trials can be run using the same testing setup because increasing the trials would give a more accurate sample of the population.

Since REEL has both RSS devices in possession and uses them both for testing, additional testing on proficiency units should be run every quarter using both devices so the ILG can be phased out and fully replaced with the B&K RSS.

Additional work could also be performed to determine the sensitivity of microphone placement within the semi-reverberant room. Specifically, looking at how far off the microphone has to be from the qualified position to affect sones. Other factors affecting room qualification could also be investigated, such as changing the angles of the baffles, to explore how their positions affect room qualification and sone values recorded.

7. CONCLUSIONS

The investigation of the effects of different microphone, specifically free-field and diffuse frequency response, on the sones recorded for a sound test show that there is no clear correlation of effect on final sone values. There was less than a 4% relative average change in sones when the microphones were compared to one another. There was no strong correlation to suggest that one microphone produced higher or lower values than the other. The study of the effects of different RSS types on final sone values found no clear correlation. The average sone values for both the ILG and B&K RSS fell within 2 standard deviations from less than 0.3 sones to 11.5 sones.

In conclusion, when comparing final sone values there is a negligible difference in the sones recorded when using a free-field and diffuse-field microphone. The difference in sone values using different RSS types is also negligible.

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APPENDIX A

SAMPLE REPORT FROM HVI

Fan Tested For: Home Ventilating Institute
Fan Model Tested:

Contract Number:
Date of Test: 7/20/2017

1. Test Point Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2. Fan Static Pressure	0.003	0.098	0.173	0.251	0.340	0.442	0.525	0.619	0.703	0.747
3. Nozzle Differential Pressure	0.246	0.230	0.258	0.267	0.292	2.799	1.560	0.612	0.775	0.751
4. Nozzle Key (ID)	4	4	4	4	4	3	3	3	1	0
5. Nozzle Static Pressure	0.002	0.097	0.172	0.250	0.340	0.442	0.525	0.619	0.704	0.748
6. Barometric Pressure (in Hg)	30.07	30.07	30.08	30.07	30.08	30.08	30.08	30.08	30.08	30.08
7. Fan Inlet Dry Bulb Temperature (F)	74.8	74.5	74.7	74.4	74.6	74.9	74.8	74.7	74.9	74.3
8. Fan Inlet Wet Bulb Temperature (F)	61.9	61.9	61.9	61.8	61.8	61.8	61.8	61.8	61.9	61.6
9. Chamber Dry Bulb Temperature (F)	74.4	74.4	74.4	74.4	74.5	74.5	74.5	74.4	74.3	74.3
10. Fan Motor Amperage	0.10	0.15	0.20	0.26	0.33	0.38	0.34	0.31	0.29	0.26
11. Fan Motor Voltage	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
12. Fan Motor Wattage	5.3	8.0	11.5	15.6	21.1	24.7	21.7	19.6	17.7	16.3
13. Fan Motor RPM	454	666	818	960	1096	1219	1344	1452	1528	1491
14. Fan Motor #2 RPM	0	0	0	0	0	0	0	0	0	0
15. Air Density at Fan Inlet (lb/ft3)	0.07421	0.07425	0.07423	0.07426	0.07425	0.07422	0.07423	0.07424	0.07421	0.07429
16. Air Density at Fan Outlet (lb/ft3)	0.07427	0.07428	0.07430	0.07431	0.07432	0.07435	0.07436	0.07440	0.07442	0.07443
17. Air Density at Nozzle Inlet (lb/ft3)	0.07427	0.07428	0.07430	0.07431	0.07432	0.07435	0.07436	0.07440	0.07442	0.07443
18. CFM at Nozzle Inlet	97.0	93.7	99.4	101.1	105.7	97.0	72.2	45.0	16.6	0.0
19. CFM at Fan Outlet	97.0	93.7	99.4	101.1	105.7	97.0	72.2	45.0	16.6	0.0
20. Fan Outlet Static Pressure	0.003	0.098	0.173	0.251	0.340	0.442	0.525	0.619	0.703	0.747
21. Fan Outlet Velocity Pressure	0.015	0.014	0.016	0.016	0.018	0.015	0.008	0.003	0.000	0.000
22. Fan Outlet Total Pressure	0.018	0.112	0.188	0.267	0.358	0.457	0.534	0.622	0.703	0.747
Values Corrected for Standard Air Density										
23. CFM at Nozzle Inlet	97.0	93.7	99.4	101.1	105.7	97.0	72.2	45.0	16.6	0.0
24. Static Pressure	0.003	0.099	0.174	0.253	0.343	0.445	0.530	0.624	0.708	0.753
25. Velocity Pressure	0.015	0.014	0.016	0.017	0.018	0.015	0.008	0.003	0.000	0.000
26. Total Pressure of Fan	0.018	0.113	0.190	0.270	0.361	0.461	0.538	0.627	0.709	0.753
27. Motor Amperage	0.10	0.15	0.20	0.26	0.34	0.38	0.34	0.31	0.29	0.26
28. Motor Wattage (as Tested)	5.3	8.0	11.5	15.6	21.1	24.7	21.7	19.6	17.7	16.3
29. CFM per Watt	18.30	11.71	8.64	6.48	5.01	3.93	3.33	2.30	0.94	0.00

Note: All pressures are in inches of water unless otherwise stated.

Figure 19: Sample Airflow Report

Test Note: Sound rpm:666

Page 1 — Contract :

HVI Sones Calculation Spreadsheet - 24-Band

Results:	0.2	Sones

Company: Home Ventilating Institute
Test Date: 7/20/2017
Model:

Line No.	Symbol	Column	17	18	19	20	21	22	23	24	25	26	27	28
		ANSI ⅓-Octave Band No.	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
		Hertz	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**
		Limits for BGD Steadiness	2	4	2	2	2	1	1	1	1	1	1	1
		Limits for SNR	10	10	10	10	10	10	10	15	15	15	15	15
		Enter Test Measurements:												
1	L_{pfm}	Meas. FAN+BGD	19.67	21.11	17.21	22.67	19.71	27.42	30.74	29.70	30.54	33.25	33.47	33.52
2	L_{pbm}	Meas. BGD	15.18	11.90	6.76	9.96	4.65	-0.49	-0.72	-0.51	-0.73	0.76	0.69	1.41
3	L_{prm}	Meas. RSS+BGD	71.31	60.96	62.77	67.51	66.29	67.17	66.43	67.07	69.50	70.75	72.59	73.33
4	L_{pbck}	Meas. BGD for check	14.06	10.93	5.85	9.36	4.15	-0.84	-0.91	-0.74	-0.76	0.38	0.47	1.25
		Check Background Steadiness and Level:												
5		2-4, Arith. Steady BGD?	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
6		3-2, Arith. RSS SNR	56.126	49.054	56.010	57.548	61.643	67.663	67.149	67.581	70.230	69.984	71.896	71.924
7	$L_{psnr,f}$	1-2, Arith. Separation (FAN SNR)?	4.492	9.211	10.448	12.709	15.059	27.914	31.452	30.213	31.265	32.488	32.778	32.110
8	$L_{psnr,z}$	Zero Sone Fan SNR (from SNR sheet)	38.577	25.716	33.162	32.101	34.195	38.313	35.601	33.633	34.082	31.937	31.549	29.579
Bands with FAN and Zero Sone Fan SNR < Limit:														
		Subtract Background measurement:												
9	L_{pr}	Log 3-2 (RSS+BGD)-BGD=RSS	71.308	60.957	62.772	67.512	66.293	67.168	66.433	67.073	69.502	70.748	72.591	73.331
10	L_{pf}	Log 1-2 (FAN+BGD)-BGD=FAN	17.767	20.559	16.799	22.434	19.571	27.412	30.733	29.701	30.534	33.250	33.470	33.514
		Calculate Room Characteristic Ratio and ⅓-Oct. Fan Sound Power:												
11	L_{wr}	RSS CAL Calibration Data (Given)	74.8	78.6	74.1	74.7	74.7	74.6	74.8	75.2	75.4	75.3	75.6	75.4
12	L_{rcr}	Arith. 11-9 (RSS pow-pres=RCR)	3.492	17.643	11.328	7.188	8.407	7.432	8.367	8.127	5.898	4.552	3.009	2.069
13	L_{wf}	Arith. 10+12 (FAN pres+RCR=pow)	21.259	38.202	28.128	29.622	27.978	34.844	39.100	37.827	36.432	37.802	36.480	35.583
		Fan Pressure at Std Distance, in Std Environment:												
14	K_{rd}	Given, dB down @ 5 feet	-14.65	-14.65	-14.65	-14.65	-14.65	-14.65	-14.65	-14.65	-14.65	-14.65	-14.65	-14.65
15	$L_{p'}$	Arith. 13-14 (Fan Test Results)	6.609	23.552	13.478	14.972	13.328	20.194	24.450	23.177	21.782	23.152	21.830	20.933
		Convert to single Sones Rating Number:												
16	s	Lookup sones for each band	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.062	0.117
17	S	Add sones & weight for **HVI Sone Rating:**					0.181							
		(Reference. Lookup table ref. column number.)	3	4	5	6	7	8	9	10	11	12	13	14

(Refer to the separate SNR calcualtion sheet for detailed SNR calculation procedure)

Figure 20: Sample Sound Report – pg 1

Test Note	Sound RPM:666		Page 2 Contract :								Company: Home Ventilating Institute Test Date: 7/20/2017 Model:			
Line No.	Symbol	Column	ANSI ⅓-Octave Band No.	29	30	31	32	33	34	35	36	37	38	39	40
			Hertz	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	6,300	8,000	10,000
			Limits for BGD Steadiness	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
			Limits for SNR	15	15	15	10	10	10	10	10	8	3	3	3
		Enter Test Measurements:													
1	*Lpfm*	Meas. FAN+BGD		33.34	27.31	20.61	18.71	16.01	11.82	9.29	7.82	7.07	6.88	6.90	6.77
2	*Lpbm*	Meas. BGD		1.81	2.49	3.01	3.33	4.01	4.69	5.42	5.97	6.40	6.70	6.83	6.72
3	*Lprm*	Meas. RSS+BGD		74.15	74.28	74.99	74.47	74.06	72.03	70.67	69.48	68.63	66.75	63.78	58.60
4	*Lpbck*	Meas. BGD for check		1.73	2.52	3.09	3.33	4.00	4.67	5.41	5.94	6.39	6.69	6.83	6.70
		Check Background Steadiness and Level:													
5		2-4, Arith. Steady BGD?		OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
6		3-2, Arith. RSS SNR?		72.339	71.790	71.980	71.143	70.053	67.336	65.252	63.509	62.234	60.051	56.949	51.878
7	$L_{panr,f}$	1-2, Arith. Separation (FAN SNR)?		31.531	24.813	17.600	15.374	11.999	7.129	3.875	1.854	0.676	0.184	0.063	0.049
8	$L_{panr,z}$	Zero Sone Fan SNR (from SNR sheet)		27.796	25.851	24.047	22.617	20.145	16.974	13.980	12.039	10.308	8.297	5.967	6.444
Bands with FAN and Zero Sone Fan SNR < Limit:															
		Subtract Background measurement:													
9	*Lpr*	Log 3-2 (RSS+BGD)-BGD=RSS		74.146	74.284	74.988	74.475	74.062	72.027	70.672	69.475	68.629	66.750	63.782	58.596
10	*Lpf*	Log 1-2 (FAN+BGD)-BGD=FAN		33.335	27.294	20.533	18.578	15.725	10.885	7.005	3.231	-1.342	-6.941	-11.489	-12.777
		Calculate Room Characteristic Ratio and ⅓-Oct. Fan Sound Power:													
11	*Lwr*	RSS CAL Calibration Data (Given)		75.7	76.1	77.1	76.7	77.1	76.6	76.6	75.9	75.5	74.6	73.4	69.2
12	*Lrcr*	Arith. 11-9 (RSS pow-pres=RCR)		1.554	1.816	2.112	2.225	3.038	4.573	5.928	6.425	6.871	7.850	9.618	10.604
13	*Lwf*	Arith. 10+12 (FAN pres+RCR=pow)		34.889	29.109	22.645	20.803	18.763	15.458	12.933	9.656	5.529	0.909	-1.872	-2.173
		Fan Pressure at Std Distance, in Std Environment:													
14	*Krd*	Given, dB down @ 5 feet		-14.65	-14.65	-14.65	-14.65	-14.65	-14.65	-14.65	-14.65	-14.65	-14.65	-14.65	-14.65
15	*Lp'*	Arith. 13-14 (Fan Test Results)		20.239	14.459	7.995	6.153	4.113	0.808	0.000	0.000	0.000	0.000	0.000	0.000
		Convert to single Sones Rating Number:													
16	s	Lookup sones for each band		0.150	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	S	Add sones & weight for HVI Sone Rating:													
		(Reference. Lookup table ref. column number.)		15	16	17	18	19	20	21	22	23	24	25	26

(Refer to the separate SNR calcualtion sheet for detailed SNR calculation procedure)

Figure 21: Sample Sound Report - pg 2

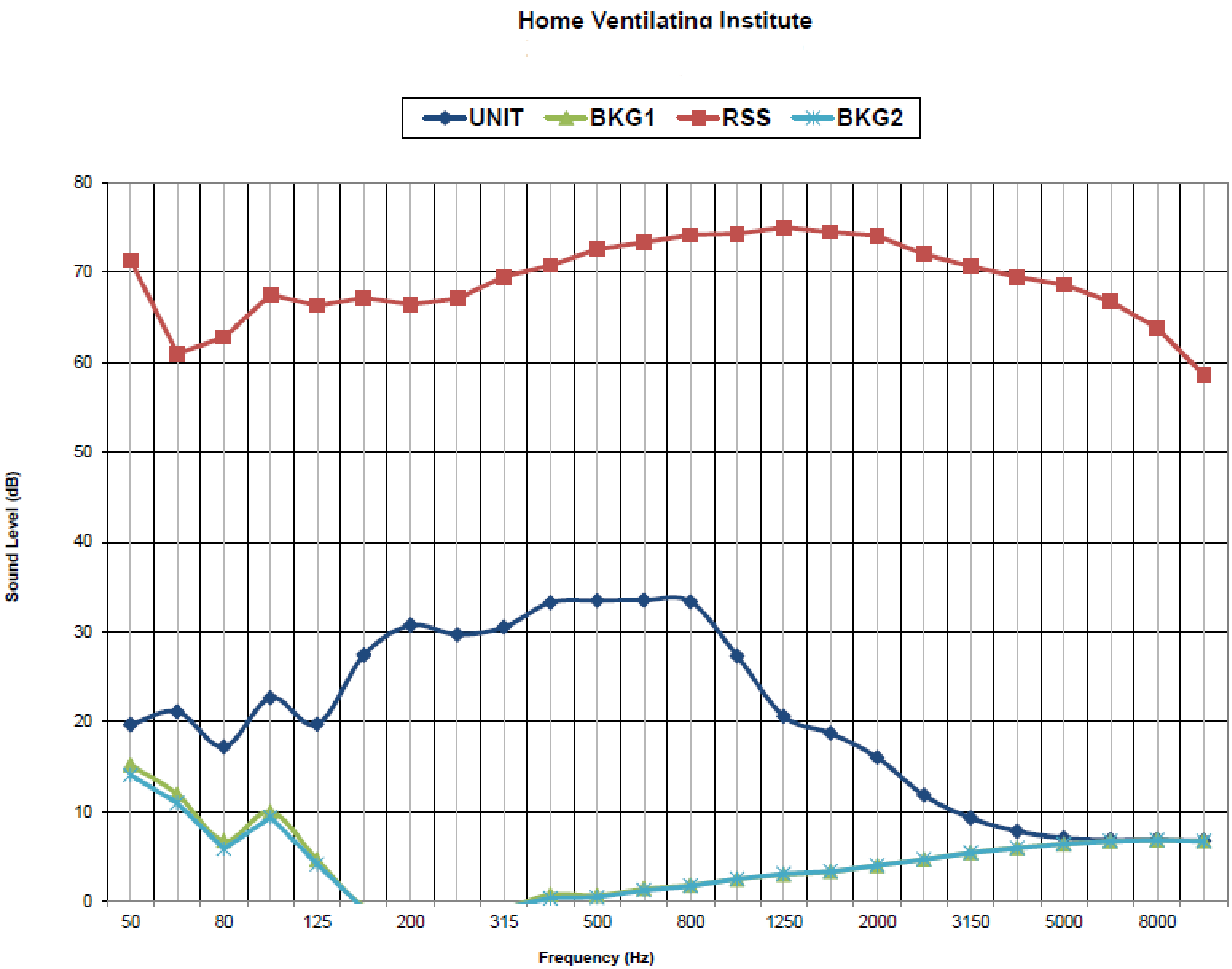

Figure 22: Sample Sound Graph for HVI

APPENDIX B

RAW DATA FROM TRIALS

Table 9: Raw Data

Model	RSS	Mic Type	
		4190	4942
<0.3 sones FV-05-11VFM5 (80 CFM)	ILG	0.277	0.269
		0.273	0.276
		0.276	0.268
	B&K	0.288	0.283
		0.281	0.275
		0.268	0.273
~1 sone FV-05-11VFM5 (110 CFM)	ILG	0.864	0.847
		0.869	0.849
		0.852	0.850
	B&K	0.828	0.829
		0.821	0.824
		0.821	0.819
2.3 sones HD80L	ILG	2.604	2.561
		2.56	2.546
		2.574	2.571
	B&K	2.575	2.551
		2.569	2.543
		2.586	2.573
5.3 sones QSE130BL	ILG	5.329	5.315
		5.334	5.326
		5.339	5.359
	B&K	5.349	5.322
		5.333	5.382
		5.401	5.419
6 sones Rangehood	ILG	6.636	6.757
		6.636	6.820
		6.662	6.808
	B&K	6.872	6.810
		6.942	6.906
		6.996	6.962
8 sones WA0876	ILG	8.204	7.807
		8.214	8.279
		8.259	8.307
	B&K	8.179	8.329
		8.184	8.283
		8.216	8.357
10 sones HCB36-6	ILG	9.636	9.566
		9.596	9.399
		9.611	9.405
	B&K	9.691	9.451
		9.764	9.568
		9.644	9.566
11.5 sones SEV24S	ILG	11.957	12.372
		12.096	12.38
		12.136	12.451
	B&K	11.963	12.464
		12.016	12.487
		12.064	12.534

APPENDIX C

RAW DATA RSS COMPARISON

Table 10: Raw RSS Data

Model	ILG			B&K				Avg	Std Dev	Relative
	Data	AVG	STD DEV	Data	AVG	STD DEV	Δ sones	Δ sones	Δ sones	Change
<0.3 sones FV-05-11VFM5 (80 CFM)	0.269	0.271	0.004	0.283	0.277	0.005	0.014	0.007	0.007	2.5%
	0.276			0.275			0.001			
	0.268			0.273			0.005			
~1 sone FV-05-11VFM5 (110 CFM)	0.847	0.849	0.002	0.829	0.824	0.005	0.018	0.025	0.007	2.9%
	0.849			0.824			0.025			
	0.85			0.819			0.031			
2.5 sones HD80L	2.561	2.559	0.013	2.551	2.556	0.016	0.010	0.005	0.004	0.2%
	2.546			2.543			0.003			
	2.571			2.573			0.002			
5.5 sones QSE130BL	5.315	5.333	0.023	5.322	5.374	0.049	0.007	0.041	0.030	0.8%
	5.326			5.382			0.056			
	5.359			5.419			0.060			
6 sones Rangehood	6.757	6.795	0.033	6.81	6.893	0.077	0.053	0.098	0.052	1.4%
	6.82			6.906			0.086			
	6.808			6.962			0.154			
8 sones WA0876	7.807	8.131	0.281	8.329	8.323	0.037	0.522	0.192	0.287	2.5%
	8.279			8.283			0.004			
	8.307			8.357			0.050			
10 sones HCB36-6	9.566	9.457	0.095	9.451	9.528	0.067	0.115	0.148	0.029	1.6%
	9.399			9.568			0.169			
	9.405			9.566			0.161			
11.5 sones SEV24S	12.372	12.401	0.043	12.464	12.495	0.036	0.092	0.094	0.012	0.8%
	12.38			12.487			0.107			
	12.451			12.534			0.083			

APPENDIX D

SUPPORTING GRAPHS

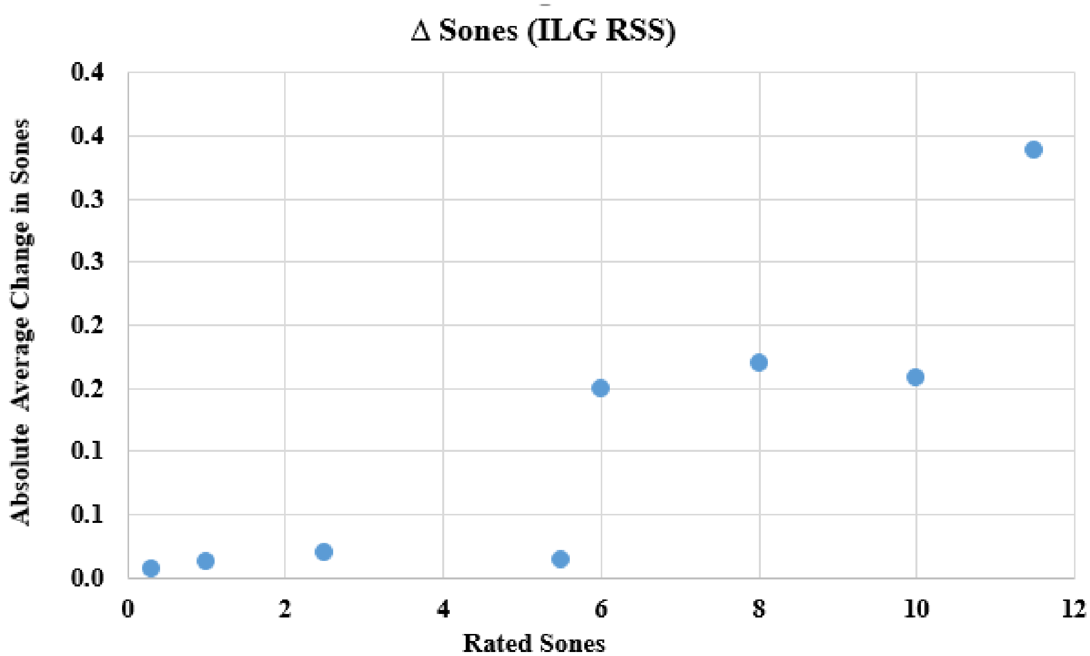

Figure 23: Absolute Average Change in Sones using ILG RSS - no trend line

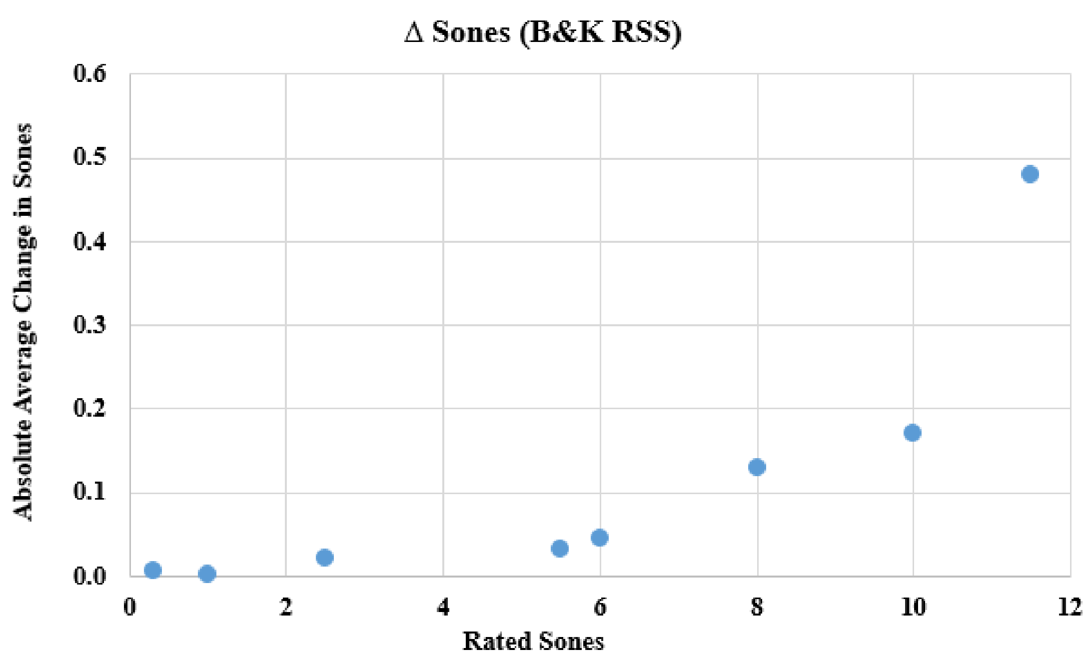

Figure 24: Absolute Average Change in Sones using B&K RSS - no trend line